

CNS Architectures and Systems Research and Development for the National Airspace System¹²

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Abstract—The need for significant improvements in communications, navigation and surveillance (CNS) for civil aviation has become more urgent in recent years. The continued growth of aviation traffic, nationally and globally, cannot be supported simply by extending current air traffic management (ATM) methods. New ATM methods and systems capable of supporting future traffic loads are under development. They require exchange of significant amounts of digital data between airborne and ground based elements of the airspace system. But the key supporting CNS infrastructure required to enable the digital data exchange does not currently exist. Therefore, the National Aeronautics and Space Administration (NASA) is undertaking a significant new project to research, develop and test new technologies to provide the CNS infrastructure needed to support future ATM for the U. S. National Airspace System and the Global Airspace System. This paper describes the new CNS research project and how CNS research fits within NASA's airspace system research program. Sub-projects being investigated for possible inclusion in the project are described and the plans for integration of the subprojects and the execution of the project are presented.

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1. INTRODUCTION

100 years after the invention of powered flight, aviation has become a major global industry. As developed countries continue to increase the availability of aviation services for transportation and shipping, and developing countries expand aviation infrastructures to spur economic growth, the face of airspace management will need to be transformed. In the United States, Europe, and parts of Asia, growing airspace congestion is threatening to strangle the growth of aviation. To combat this problem, new systems are being developed and implemented to increase the operational efficiencies of the system and accommodate near-term growth. Significant changes in how the airspace is managed are envisioned for long-term growth. Researchers in the United States, Europe, and elsewhere are developing new airspace management techniques and supporting systems that will support the long-term growth envisioned.

The key underlying aviation infrastructure, aside from the physical facilities such as airports, runways, and control towers, is the communications, navigation and surveillance (CNS) systems that enable the safe operation of large numbers of aircraft simultaneously within the airspace system. Current CNS systems in use today have evolved over many decades of development. They generally have been developed one at a time, in response to particular needs and requirements, with each requiring their own airborne and ground systems. They are based on analog technology and are difficult to integrate into a modern network-based information centric system. However, network-based digital information is needed to enable the effective functioning of the new airspace management systems being developed for the long term. Hence, a research and development effort for a future CNS infrastructure, in parallel with the airspace system management research is

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needed. NASA's Advanced CNS Architectures and System Technologies (ACAST) Project has been established to help fill this need.

The ACAST Project is focusing on the need to transition from current systems, including those already deployed and those in the implementation "pipeline", to the future CNS infrastructure required to enable the advanced airspace management systems envisioned for providing air transportation growth for most of the 21st century. This will involve development of near and mid-term technologies that provide solutions to emerging system problems while also providing a path for long term CNS infrastructure development. Such technologies would not become obsolete with the implementation of the long term infrastructure and so will have a much higher likelihood of being adopted, compared to technologies with a relatively short lifespan requiring eventual replacement.

The first year of the project, beginning 1 October 2003, is a program definition year. A number of potential research and development areas are being investigated for their possible execution in the remaining 5 years of the project. The benefits, importance, and required resources for these research areas will be defined, leading to the selection of sub-projects to be executed by the ACAST Project. The following sections will discuss NASA's overall program in airspace systems research and the CNS elements it contains, known CNS research needs, the planned structure of the ACAST Project and the sub-projects that have been proposed, and how the Project will proceed in the future.

2. NASA AIRSPACE SYSTEMS RESEARCH AND CNS RESEARCH ELEMENTS

NASA's Airspace Systems Program has the goal of enabling major increases in the capacity and mobility of the air transportation system through development of revolutionary concepts for operations and vehicle systems. The three primary objectives supporting this goal are:

- Improve throughput, predictability, flexibility, collaboration, efficiency, and access of the NAS
 - Enable general aviation and runway-independent aircraft operations
- Maintain system safety, security and environmental protection
- Enable modeling and simulation of air transportation operations

The Program is accomplished through 8 Projects described as follows:

The Advanced Air Transportation Technologies (AATT) Project will end in 2004. Its goal is to improve the capacity of transport aircraft operations at, and between, major airports in the National Airspace System by:

- Developing decision support tools to help air traffic controllers, airline dispatchers, and pilots improve the air traffic management and control process from gate to gate
- Defining, exploring, and developing advanced shared-separation ATM concepts

The Small Aircraft Transportation System (SATS) Project will be completed in 2005. Its goal is to develop and demonstrate technologies to enable increased utilization of local & regional airports to enhance mobility, and to demonstrate the following operating capabilities:

- Higher Volume Operations (HVO) in Non-Radar Airspace and at Non-Towered Airports
- Lower Landing Minimums (LLM) at Minimally Equipped Landing Facilities
- Increase Single-Pilot Performance (SPP) Crew Safety & Mission Reliability
- En Route Procedures & Systems for Integrated (ERI) Fleet Operations

The Virtual Airspace Modeling and Simulation (VAMS) Project, to be completed in 2007, is intending to provide the technologies and processes for conducting trade-off analyses amongst future air transportation system's concepts and technologies, with the following primary objectives:

- Model and simulate behavior of air transportation system concepts and their elements
- Develop advanced air transportation operational concepts
- Conduct assessments of advanced air transportation concepts

The Human Measures and Performance Project (formerly known as Airspace Operations Systems) is an on-going base research project currently planned through 2009. Its goal is to develop fundamental knowledge, models, and tools for the efficient and safe operation of aviation systems by their human operators, in the areas of:

- Human/automation integration research
- Human error and countermeasures
- Psychological/physiological stressors and factors

Four new projects have entered a project definition stage in fiscal year 2004 (beginning 1 October 2003) and funded through 2009.

The Efficient Aircraft Spacing Project includes Airborne Separation, Shared Separation, Wake Vortex Solutions, and Wake Vortex Alleviation sub-projects.

The Efficient Flight Path Management Project has two sub-projects: Integrated Traffic Management Tools and Airborne Traffic Management Tools

The Strategic Airspace Usage Project contains the Strategic Flow Management sub-project.

The Spaced Based Technologies Project contains the CNS Technologies and Architectures sub-project. This Project encompasses the work being referred to as ACAST in this paper, as the official project name cannot be updated until the next budget cycle.

The AATT and VAMS Projects contain CNS research elements which have supported those projects goals while also providing the foundation for the development of ACAST.

In AATT, the Advanced Communications for Air Traffic Management (AC/ATM) effort has focused on developing technologies for the use of satellite communications for ATM applications, and on demonstrating the feasibility of ATM data applications over satellite communications links. It has also developed future CNS requirements, CNS architectures to support those requirements, and concepts for hybrid communications system architectures.

For VAMS, models for CNS system elements are being developed for integration into the Virtual Airspace System Technologies toolbox, which will enable the simulation and modeling of advanced air transportation concepts.

In the SATS project, technologies for network-based communication of CNS information are being demonstrated. This will enable aircraft to have access to smaller facilities which do not have the sophisticated air traffic management infrastructure of larger airport.

3. REQUIREMENTS FOR CNS

It has become accepted in the aviation community that significant improvements in communications capabilities are required to enable improved efficiency, safety and capacity of the airspace system. The most obvious example is the congestion of the VHF frequency band (118-137 MHz) in which the majority of aircraft to ground communications occurs. In Europe, the 25 kHz channels assigned to voice communications have been split into 8.33 kHz channels to provide more capacity. However, continued air traffic growth, and the need for more data communications to support future services and ATM systems dictate that this solution will provide only temporary relief.

NASA has been performing research and development on future air traffic management concepts, methods, and technologies under several projects, as described above. At NASA's Glenn Research Center, attention has been focused on the communications architectures and technologies necessary to support advanced ATM concepts. Several studies sponsored under by NASA Glenn have indicated

that significant new requirements for the CNS infrastructure will continue to emerge. In particular, more data transmission between all airspace system entities and more interconnectivity between these entities will be required. As international travel and global airline operations increase, greatly improved global interoperability of CNS systems is also needed.

As with the introduction of 8.33 kHz voice channels, an initial move to digital communications is beginning to take place with the introduction of VHF Digital Link (VDL) Mode 2 for airline operational communications links. VDL Mode 3, providing digital voice and data, and VDL Mode 4, providing digital data for air-to-air communications, are also being proposed. Such efforts are aimed at extending the capacity of the VHF spectrum and supporting basic digital data services. However, long-term integrated CNS infrastructures capable of supporting extended growth and advanced ATM techniques will require technologies beyond the VDL Modes.

Studies sponsored by NASA Glenn show that requirements for the CNS infrastructure will require some new systems to be implemented. They have concluded that a network-oriented hybrid of satellite and ground-based communications systems will provide the most logical and potentially most cost effective architecture to support future requirements.^{1,2,3} In a previous paper, a division of applications between the satellite and ground-based segments was suggested, as summarized in Table 1⁴.

Navigation systems for aviation are migrating from ground-based navigational aids to satellite based systems utilizing the GPS constellation. The development of wide area and local area augmentation systems to provide the necessary accuracy and reliability is proceeding. The effective use of satellite-based navigation for ATM is evolving. The possible vulnerability of satellite-based navigation to interference, jamming and system failure requires that some backup systems must be developed to create a robust system. In the meantime, most of the ground-based navigational aids will need to remain in place. However, it would be desirable to reduce or eliminate these aids due to the very high cost of maintaining the ground-based infrastructure.

Surveillance in the airspace system uses both non-collaborative primary radar and collaborative secondary surveillance. An emerging technology is Automatic Dependent Surveillance, in which GPS-derived position and intent data are transmitted by aircraft for use by ground controllers and potentially by other aircraft. Considerable development efforts have occurred for ADS, and the US Federal Aviation Administration is currently evaluating ADS technology in Alaska. As with navigation systems, current systems, particularly primary radars, will need to remain in place for the foreseeable future, especially since only non-collaborative radars provide the required security.

Table 1 – Possible Division of Applications between Satellite and Ground-based Communications

| | | Satellite-based Applications | Ground-based Applications |
|--------------------|--|---|--|
| ATM Communications | Air Traffic Control (ATC) Communications | En-Route ATC Data Controller-Pilot Data-Link Communications (CPDLC) | Terminal Area and Surface ATC (CPDLC) |
| | | En-Route Automatic Dependent Surveillance (ADS) | Terminal Area and Surface ADS |
| | | En Route (National) Traffic Information Service (TIS) | Terminal Area (Local) TIS |
| | Advisory Services | Weather Sensor Data Downlink | |
| | | En-Route (National) Flight Information Service (FIS) | Terminal Area FIS |
| | Airline Operation Communications | En-Route Airline Dispatch and Administration | Terminal Area Airline Administration |
| | Other Non-passenger Communications | En-Route Aircraft Health/Maintenance | Surface and Terminal Area Health/Main-tenance |
| | | En-Route Security, Surveillance “Black Box” | Terminal Area Security, Surveillance “Black Box” |

ADS systems add considerably to the amount of data the CNS infrastructure is required to handle, and also require a significant investment in ground infrastructures. Space-based methods of surveillance, which can be collaborative or non-collaborative, are possible alternatives.

Oceanic and remote regions, where the installation of ground-based facilities is impossible or unfeasible, also exhibit growing air traffic. Cost-effective methods of

providing communications and surveillance adequate for control of oceanic and remote area traffic on the same basis as for domestic airspace are needed, and could provide significant capacity, efficiency and safety benefits.

As these discussions indicate, the CNS infrastructure is gradually moving from analog to digital systems. As internet networks have transformed global communications, a network-based approach to a digital CNS infrastructure is needed to transform global aviation and allow the needed ATM improvements. The development and demonstration of a global aviation network architecture and supporting standards based on internet protocols is needed to begin the transformation process. But the implementation of such a global aviation data network must enable the transition to a future integrated CNS infrastructure by accommodating current and planned CNS systems. The high cost of installing new avionics systems on existing aircraft, and the 20 to 30 year lifetime of commercial transport aircraft, ensures that such an accommodation is necessary.

Avionics cost is perhaps the most significant driver in the acceptance of new systems by the user community. Current CNS systems can require 20 or more avionics components. Planned new systems will require even more components. The equipment demands are beyond the affordability of airlines, and also impose weight and space problems in aircraft. Tables 2 and 3 summarize existing and potential future aircraft equipment requirements⁵. Methods to reduce aircraft equipment requirements through integration of functions and employment of multi-mode avionics technologies are needed.

4. THE ACAST PROJECT

The ACAST Project is planned to be a six year project, from 1 October 2003 to 30 September 2009, corresponding to the US Government fiscal years of 2004-2009. However, the first year is a project formulation year during which a number of proposed subprojects will be investigated and evaluated for inclusion in the project. The subprojects are described in detail in the following section.

During the project formulation year, the ACAST Project's stated goal is to initiate the transition of today's CNS systems into a high-performance network-centric digital infrastructure to support the transformation of the National Airspace System. This corresponds to the statements above that ACAST is intending to develop technologies which can be implemented within near to mid term time frames (i.e. 6 to 12 years) to address emerging airspace system needs while simultaneously developing the long term CNS infrastructure such that the near and mid-term solutions are also part of the long term solution..

Table 2 – Summary of Existing Aircraft Equipage Requirements

| Existing Aircraft Equipage Requirements | | |
|---|-----------------|----------|
| | System | Quantity |
| Communications | HF Comm | 2 |
| | VHF Comm | 3 |
| | ACARS | 1 |
| Navigation | DME | 2 |
| | ADF | 2 |
| | VOR | 2 |
| | ILS | 2 |
| | MLS | 2 |
| | Inertial Ref. U | 3 |
| | ATC Xpndr | 2 |
| Surveillance | TCAS | 1 |

This requires that the long-term CNS infrastructure architecture is sufficiently understood. Hence, a key element of ACAST will be the development and analysis of CNS requirements and architectures. The long term architecture, based on airspace system operational concepts, will provide the focal point for a transitional architecture strategy that will enable the ACAST goal to be met.

The ACAST objectives intended to fulfill the goal, are the following:

- Identify the transitional architecture to achieve the transformational high-performance integrated CNS (ICNS) system and define the global air/ground network architecture
- Develop efficient aviation spectrum utilization and support global spectrum allocations
- Enable efficient oceanic/remote operations through improved comm and surveillance
- Increase air-ground datalink performance and capacity for terminal and en-route operations
- Improve airport surface operations via an integrated wireless CNS network

In its definition phase, ACAST will consider problems and potential solutions for each of the key domains of flight: the airport surface, the terminal area, the en-route domain, and oceanic and remote areas.

Table 3 – Summary of Future Aircraft Equipage Requirements

| Future Aircraft Equipage Requirements | | |
|---------------------------------------|-------------------|----------|
| | System | Quantity |
| Communications | VDL Mode 2 | 2 |
| | VDL Mode 3 | 2 |
| | SATCOM | 2 |
| | 25/8.33 KHz Voice | 3 |
| Navigation | VHF LAAS | 2 |
| | DGPS | 2 |
| | SCAT-I | 2 |
| | FIS-B | 1 |
| Surveillance | ADS-B | 2 |
| | 1090 Squitter | 2 |
| | UAT | 2 |
| | TIS-B | 1 |

5. PROPOSED CNS TECHNOLOGY SUBPROJECTS

In its project definition year, the ACAST Project will investigate the following subproject areas:

1. Transitional CNS Architectures
2. Global Air/Ground Networks
3. Spectrum Research
4. Oceanic/Remote Communications and Surveillance
5. Multimode/Multifunction Avionics
6. VHF Systems Optimization
7. Terminal Area Communications
8. Surface ICNS Network
9. Space-based Surveillance
10. CNS Technologies

A description of each proposed subproject is now given, with a summary of subproject presented in Table 4.

Transitional CNS Architecture

The long term architecture for the national and global airspace system is emerging from operational concepts recently developed or still under development. However, key requirements for this architecture will be found to be common among most of the operational concepts. Increased integration of digital CNS functions, full air/ground network

connectivity, high capacity, global coverage, and efficient use of spectrum will be necessary.

The transitional CNS architecture will be developed to provide a path from current and planned CNS systems to a future integrated CNS digital infrastructure. This architecture will provide one of three guiding frameworks for the other technology developments under ACAST.

Global Air/Ground Networks

The global air/ground network is the backbone of the future CNS infrastructure, enabling full sharing of CNS data among all relevant users in an efficient, reliable and timely manner. The standards and protocols for the global air/ground network are emerging, and are likely to ultimately conform to modern internet networking techniques.

The key research and development efforts required to bring the concept of a global air/ground network to a demonstration level will be developed in this sub project. This subproject is the second of the three guiding frameworks for other technology developments in ACAST.

Spectrum Research

Demands on the aviation spectrum continue to increase. Simultaneously, pressure from interests external to aviation to reduce aviation spectrum allocations threaten to severely constrain future aviation growth.

Research on efficient spectrum usage, mapping of spectrum requirements to future aviation CNS requirements, and the development of technologies to meet future CNS needs within current aviation spectrum, and the national and international coordination of aviation spectrum use and protection are being investigated in this subproject. Spectrum Research is the third of the guiding frameworks for other technology developments in ACAST.

Oceanic/Remote Communications and Surveillance

The lack of direct communications and surveillance between aircraft and oceanic control centers results in the necessity of very wide spacing of aircraft in oceanic and remote regions. Although many aircraft are equipped with some satellite communications capabilities, a low cost communication solution is needed to bring the level of overall aircraft fleet equipage to a high enough point to allow reduced oceanic and remote aircraft separation. Such equipage would allow a significant cost and efficiency improvement while maintaining or improving overall safety.

The Oceanic/Remote Communications and Surveillance subproject will investigate satellite communications component and system technologies that can provide lower cost direct communications between aircraft and controllers to enable the benefits of reduced spacing.

Multimode/Multifunction Avionics

Current avionics are not interoperable with multiple CNS modes and multiple national standards, are expensive to upgrade and certify, are not easily reconfigurable for new CNS functions and/or modes, and are not able to provide user-selected integration of C, N, S and management functions. The introduction of improved CNS systems into aviation is stifled by the high cost of avionics upgrades.

A promising approach, to be investigated in this subproject, involves the use of software-defined-radio and other technologies to enable a multimode/multifunction avionics system which can enable interoperability across a range of CNS systems within a single box. Future re-programmability, easy insertion of new component modules, and reduced life-cycle costs are possible. This subproject will investigate the development of an architecture and prototype for multi-function multi-mode digital avionics (MMDA) that demonstrate: interoperability with international standards and operational modes; low life-cycle cost to equip/modify; compliance with existing and next gen. air/ground and air/air CNS requirements & functions; and comply with redundancy, certification and safety standards.

VHF Systems Optimization

Limited VHF communications system capacity and increasing air traffic results in congestion of the aviation VHF spectrum. The resulting voice communication errors and delayed channel access create system congestion and air traffic delays. Future growth in the near and mid-term time frames will be constrained because airspace operations will continue to be highly dependent on VHF systems until new CNS systems in other frequency bands can be implemented.

This subproject will investigate potential improvements to optimize the performance of current and planned VHF systems to mitigate the constraints imposed by VHF frequency congestion until new CNS system capacity can be established in other frequency bands.

Terminal Area Communications

Communications requirements for air traffic management are heaviest in the terminal area domain due to the high density of air traffic and the need for much highly localized

information, such as weather and traffic, for aircraft arriving and departing from airports. Demand for digital air/ground (A/G) communications in the terminal area will continue to increase rapidly due to continued increases in air traffic density and the need to implement advanced terminal area automation systems. Long range NAS operational concepts indicate a need for wideband terminal area communications that present and emerging A/G systems cannot meet.

The Terminal Area Communications will perform initial research and development on robust, next-generation, wireless, and wideband, air/ground communications technologies that will meet the future requirements for terminal area aviation air traffic management communications and enable safe future terminal area capacity growth.

Surface ICNS Network

There is a recognized need for significant improvement in the movement of CNS data on the airport surface. Current surface systems use VHF communications for voice only (no data) that are limited in their capabilities to enable future system automation and decision support systems, and use an aging obsolete physical communications infrastructure that is vulnerable to outages and costly to maintain and upgrade. Nearly every airport suffers from infrastructure problems which add to operational costs and constrain operations and capacity growth. A wireless network-based infrastructure is a potential solution to these problems.

The Surface ICNS Network subproject has the goal to develop and demonstrate a wireless/hybrid surface integrated CNS network prototype that enables transfer of mission critical airport voice/data among users and service providers; transfer of non-critical information among aircraft, tower, airport and airline operators; interoperability with existing and future systems and uses open systems and commercial standards; required redundancy and reliability, scalability, flexibility and upgrades; and seamless integration with terminal communications.

Space-based surveillance

Accurate and precise aircraft position is not uniformly available in all places through present cooperative and non-cooperative surveillance capabilities. Constraints in system capacity result due to an inability to reduce aircraft separation minima. Several space-based technologies have the potential to relieve the constraints by providing high resolution global coverage.

The space-based surveillance subproject will examine the alternatives available for space-based surveillance, analyze cost and potential benefits, and analyze the impact on future

air traffic management systems and global CNS infrastructure of a space-based surveillance system.

Table 4 – Highlights of Proposed CNS Technology Subprojects

| Proposed Subproject | Highlights |
|--|--|
| Transitional CNS Architectures | The CNS infrastructure architecture providing the transition from the current infrastructure to the long-term fully digital system |
| Global Air/Ground Networks | Network architecture, standards and protocols to define a future digital CNS network |
| Spectrum Research | Future aviation spectrum requirements, long term aviation spectrum planning, and efficient spectrum usage |
| Oceanic/Remote Communications and Surveillance | Communications and surveillance system sufficient to allow safe reduction in oceanic spacing of aircraft |
| Multimode/Multifunction Avionics | Reduce avionics life-cycle costs and increase interoperability by applying software defined radio and other technologies to enable multi-function avionics |
| VHF Systems Optimization | Optimize performance of current and planned VHF systems |
| Terminal Area Communications | Develop concepts for the next generation air-ground digital communications systems in the terminal area |
| Surface ICNS Network | An integrated CNS network for the airport surface providing capacity for all airport users |
| Space-based Surveillance | Study the potential impact of space-based surveillance technologies on NAS operations and future CNS architectures |
| CNS Technologies | Investigate and perform research and development of selected high-risk, high-payoff CNS technologies |

CNS Technologies

The CNS Technologies subproject will examine select high-risk, high-payoff technologies with a potential for major advancements in airspace system performance. It is intended within ACAST to fund some long-term research

areas to support long-term development of the CNS infrastructure. Possible areas of research include advanced antennas for aeronautics, satellite communications network technologies, advanced landing navigation technologies, and GPS augmentation and backup technologies.

FUTURE DIRECTION OF THE ACAST PROJECT

During the ACAST Project's project definition year, the 10 subproject areas are being investigated to understand system requirements, possible architectures and applicable technologies, cost/benefit analyses, and research and development approaches. Systems studies are being funded to address these issues. ACAST Project staff members are analyzing the results and developing subproject plans and assessing the required resources to complete subproject goals. The test and demonstration requirements are also being assessed and plans for development of the appropriate facilities are being created.

Prior to the start of the ACAST Project's second year, subprojects will be prioritized and matched against the available project resources. It is likely that some subprojects will be eliminated or reduced in scope due to resource limitations. However, subprojects not developed under ACAST will be submitted to new project formulation activities for funding under a future project. The final 5 year ACAST Project Plan will be developed based on the results of the prioritization and selection process.

ACAST will continue to rely on subprojects providing the framework for the architectures, networks, and spectrum needs future CNS infrastructure requirements in order to guide the component and system technology subprojects. Test and demonstration facilities, including simulation and modeling, will be developed to simultaneously support all subproject needs. These facilities will also be shared or used jointly with, other facilities in the aviation community to strengthen overall demonstration and test value. Efforts are in place to collaborate with the aviation community in the ACAST effort to leverage efforts of other organizations to provide maximum results from the available resources, and to develop products that are supported and accepted by the national and global aviation community.

SUMMARY

The US Government has recognized the need for major improvements in how the national airspace system is managed. The communications, navigation and surveillance systems are a key supporting infrastructure which requires significant upgrading in order to support the airspace system management improvements. NASA has initiated a project, called ACAST, to perform research and development to initiate the process of upgrading CNS systems and the

overall architecture to provide a high performance, network centric digital CNS infrastructure.

The ACAST Project began 1 October 2003, and in the first year is investigating 10 subprojects for possible inclusion in the project's remaining five years. The subprojects include cross-cutting areas to provide development framework for the project in the areas of integrated CNS architecture, global network, and spectrum requirements. Component and system technologies being investigated include multimode/multifunction avionics, airport surface and terminal area communications, VHF system technologies, space-based surveillance, oceanic communications and surveillance, and advanced CNS technologies. At the conclusion of these investigations, subprojects will be selected for full development in the ACAST Project's remaining five years based on subproject priority and cost.

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